NEW INSTRUMENTATIONS AND METHODS FOR THE LOW FREQUENCY PLANETARY RADIO ASTRONOMY

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Abstract

Over the past years the interest for the low frequency radio astronomy has been growing considerably. Among several fields of investigation this astronomical branch covers the solar system radio astronomy, which includes investigations of the Sun,the solar wind, solar–terrestrial relations, and planets (investigations of planets includes also to some extend studies of exoplanets). The largest decameter wave instruments UTR–2, URAN, and Nançay Decameter Array with new highly efficiently back–end facilities (such as digital spectral processors) have yielded a lot of interesting scientific results. New astrophysical programs, methods, and techniques are considered in the frame of future developments of very low frequency radio astronomy, including a new generation of ground–based and space–borne radio telescopes.

1 Introduction

The planetary radio astronomy presents one of the most important part of the low frequency radio astronomy in general. The methodical aspects of the radio astronomical investigations are also true for other objects in the solar system and galaxy due to their similarity of radio emission parameters and, in some cases, the similarity of the physical processes and generation mechanisms. So, the list of the investigated objects includes: the planets (first of all, Jupiter with the decameter radiation as the only emission until now to be observed by the ground–based technique); the Sun (bursts, CME); interplanetary medium; the Moon (passive and active investigation methods); the Earth (active and passive methods of the ionosphere and magnetosphere researches); comets (disturbances of the interplanetary medium); exoplanets; flare stars; pulsars; the unknown sources of the sporadic decameter radiation.

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Radio emission of the planets and of many others radio astronomical objects is characterized by the very high time scales variations, the fine spectral structure particularities, and the wide–band radiation. Due to this, the continuum wide–range long time period measurements of the dynamic spectra with high frequency and time resolution are the most informative one. The parameters of the ground–based receiving–recording equipments and telescopes have to be as follows:

- Frequency band F=1030 MHz (up to 100 MHz).
- Instant analysis band $B \geq 10$ MHz.
- Time resolution $\Delta t \leq 1$ ms.
- Frequency resolution $\Delta f \leq 1$ kHz.
- Number of channels $N \geq 1000$.
- Dynamic range $D \geq 70$ dB.
- Time of continuous observations $T \geq 1$ hour.
- Sensitivity $\Delta S_{\mathrm{min}} \leq 1$ Jy.
- Instant effective area $A_{\mathrm{eff}} \geq 10^4$ m^2 (up to 10^6 m^2).
- Polarization has to be orthogonal or circular.

It must be noted that the decameter range is extremely difficult for radio astronomical observations. Natural and artificial sources of interference are very numerous and often much more intensive than space radio emission. The influence of the medium (ionosphere, interplanetary and interstellar space) is very strong. This leads to absorption, refraction and scattering of radio waves. Also in the decameter range the brightness temperature of non–thermal galactic radio emission is very high. These above mentioned well–known existing difficulties in the ground–based decameter radio astronomy need to be solved by the use of special equipments and methods. The main problems of the decameter radio astronomy and possible ways of the prevented exposures removal are shown in Figure 1. One of the favorable factor is that many new technical specifications need to be realized for astrophysical processes investigation allow to reduce the negative exposures during the experiments. This is true for the high dynamic range, high time and frequency resolution of the used broadband back–end. Such approach not only gives the possibility to get the maximum information of the radio emission object, but also to measure it under conditions of intensive monochromatic and pulse interferences.

In the present work new instrumental and methodical aspects of the investigations of the planets and the other astrophysical objects by the ground–based decameter observations are considered. The results of these modern experiments are presented. The perspectives of the present and future investigations with the new instrumental and methodical techniques are finally discussed.

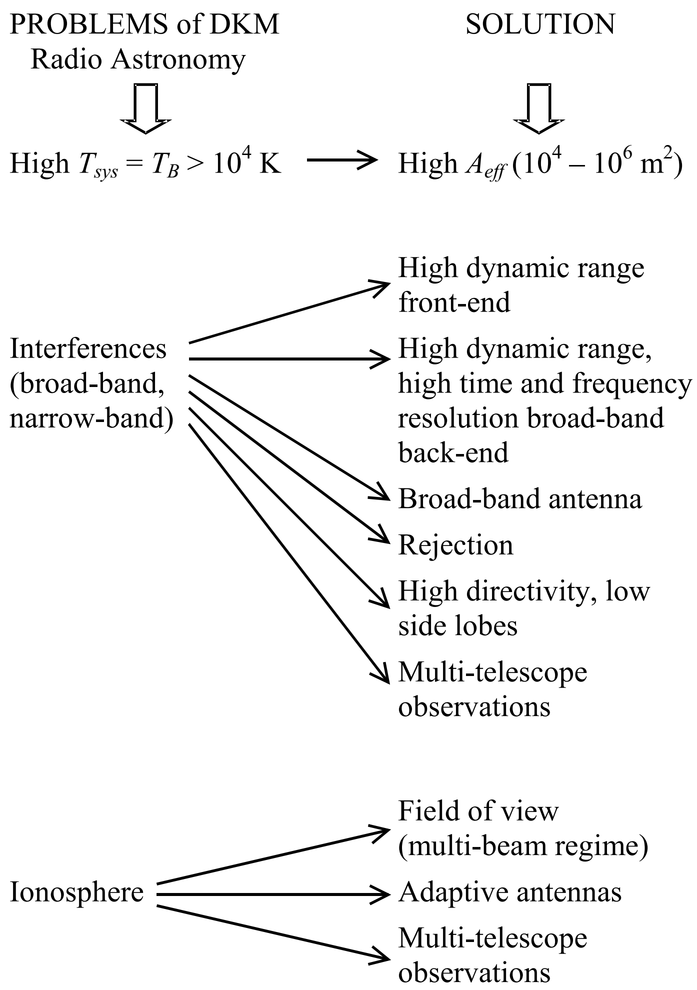

Figure 1: Main problems of the decameter radio astronomy and solutions.

2 UTR–2, URAN radio telescopes and Nançay Decameter Array: a useful step towards ground–based low–frequency radio astronomy development

Radio astronomical investigations of planets and the other objects at the decameter wavelengths are carried out during the last years by the use of different types of radio telescopes. In the present time the more effective instruments for such investigations are the Ukrainian radio astronomical systems UTR–2 and URAN, and also the Nançay Decameter Array (France). These facilities are in accordance to the necessary requirements. They are actively used for the planetary and Solar investigations and are very comfortable for the approbation of new ideas and methods leading to the perspective development of the decameter radio astronomy and also to the creation of giant, ground–based, low frequency, new generation radio telescopes. A corresponding approach was realized during the performance of an international project INTAS 97 - 1964 " New frontiers in decameter radio astronomy" (France - Austria - Ukraine - Russia) [Konovalenko et al., 2000; Lecacheux et al., 2000, Rucker et al., 2001].

In the beginning of the 1970's the Ukrainian T–shaped radio telescope, second modification (UTR–2) was built near Kharkov [Braude et al., 1978]. It has the following parameters:

- Operating range: 8–40 MHz.
- Beam width at 25 MHz for zenith direction: $25'$.
- Maximum effective area: 150000 m^2.
- Number of array elements: 2040.
- Sector of beam steering: $\pm 70°$ from zenith for both coordinates.
- Time of electrical beam directing to every point of the sector: less than 0.1 s.
- Step of beam movement: about $4'$.
- Total number of beam positions in the sector: about 2×10^6.
- Number of simultaneously working beams: 5–8.
- Side lobe level: regulated in the range from -13 dB to -30 dB.
- System temperature corresponding to brightness temperature of galactic background: about 30000 K at 25 MHz.
- Sensitivity (3–σ level, band width of 10 kHz, integration time 60 s): about 10 Jy at 25 MHz.

It is possible to work simultaneously at every frequency of the operating range and independently using the North–South (1800 m $\times$ 60 m) and West–East (900 m $\times$ 60 m) antennas. The outlook of North–South UTR–2 antenna is shown in Figure 2. The radio telescope structure is flexible and provides an easy change between configuration and working modes. With outputs of eight sections of the North–South antenna, four sections of the West–East antenna, and corresponding equipment, it is possible to get different beam patterns and different UV plane filling (UV plane is the region of spatial frequencies, i.e. a spatial-frequency response of radio telescope).

The Kharkov radio telescope is equipped with various analog and digital devices for reception and registration. They are correspondingly used to perform scientific programs. The telescope equipment includes multi–channel receivers of continuous emission, correlation spectral analyzer, acoustic–optical analyzer, dynamic spectrographs, polarization measurement devices, a heliograph, magnetic tape recorders and computer systems for data collecting. The telescope is controlled by using personal computers [Konovalenko, 2000].

Figure 2: UTR–2 antenna array in North–South direction.

Figure 3: Distribution of URAN elements in the Ukraine.

On the base of the radio the telescope UTR–2, the decameter VLBI system URAN was built [Megn et al., 1997]. Besides the UTR–2, it includes four others radio telescopes of smaller size. URAN–1 and URAN–4 belong to the Institute of Radio Astronomy. URAN–2 belongs to the Gravimetric Observatory of NASU (Poltava) and URAN–3 belongs to the Institute of Physics and Mechanics of NASU (Lviv). Figure 3 shows the distribution of URAN elements on the Ukraine territory. The system has several base lines varying from 40 km to 900 km. The angular resolution reaches 1 angular second (which corre-

Figure 4: URAN–2.

Figure 5: URAN–3.

sponds to the fundamental limit imposed by scattering in the interstellar medium at these frequencies). Images of URAN–2 and URAN–3 antennas are shown in Figures 4 and 5.

The Decameter Array in Nançay (France), which is mainly used for daily monitoring of Jupiter and solar corona activities at decameter wavelength, is an example of a large, low–cost, planetary dedicated radio telescope (see Figure 6). It consists of 144 helix spiral, wide band elementary antennas filling an aperture of about 10^4 m^2. The antennas are

Figure 6: Nançay Decameter Array.

arranged in two sub–arrays in opposite senses of circular polarization. The measured effective area of each sub–array is 4000 m^2 at 20 MHz. This leads to the possibility of polarimetric measurements. The total bandwidth of the instrument covers 10 to 85 MHz. The instantaneous bandwidth is one octave and the useful tracking time is 8 hours per day for the declination $\delta = 0°$. Several specialized, digitized spectrographs (with broadband frequency coverage, high time and spectral resolution capabilities) can simultaneously be operated, including new generation receiver - real–time high dynamic range digital spectral analyzer. The Nançay Decameter Array adapts optimally for continuous, fully automated Sun and Jupiter sporadic radio emission monitoring and for some other astrophysical tasks, compatible with its relatively small antenna aperture [Lecacheux, 2000].

3 Some new results of observations and tests

Progress in the development of the electronic, telecommunication and computer technique provides now the essential possibility to increase the quality and efficiency of the radio astronomical investigations at decameter wavelengths. During the last years significant modernization of the back–end facilities has been made for the above mentioned antennas. Comparative characteristics of the existing recording technique are shown in Table 1. The technical parameters designation in Table 1 corresponds to those marked in Section 1. The devices are coded as follows:

- DAC is the digital autocorrelometer.
- AOS is the acousto–optical spectrum analyzer.
- DSP is the digital spectral processor.

Table 1: Back–end facilities

	D	B	Δt	Δf	N	Time of cont. obs.
Filter bank	+	+	+	–	–	+
Swept analyzer	+	+	–	∼	+	–
DAC	–	+	∼	+	+	+
AOS	∼	+	∼	∼	+	+
DSP	+	∼	+	+	+	+
Waveform anal.	+	∼	+	+	+	–

Sign (+) corresponds to the possibility of obtaining the maximum high value of the parameter; sign (–) corresponds to the opposite situation; sign (∼) corresponds to the possibility of obtaining some middle value (quality).

One can see from Table 1 that the digital spectral processors are the most useful for the actual modern problems of low frequency planetary radio astronomy. For instance, the DSP digital spectral polarimeter [Kleewein et al., 1997; Lecacheux et al., 1998b] provides the ultimate spectral analysis capability of the astronomical instruments. Unlike existing analyzers, the new instrument performs spectral analysis digitally in real–time using digital signal processing (DSP) techniques. Both theoretical study and practical experience have shown that such an approach offers significant advantage over conventional analyzers, namely swept frequency analyzers, filterbanks, acousto–optical spectrometers or autocorrelometers. None of these systems indeed can simultaneously provide wide bandwidth, high time and frequency resolutions, high dynamic range and no loss in sensitivity.

This DSP device that has been developed can operate down to a time resolution of one millisecond with 1024 frequency channels over an instantaneous bandwidth of 12.5 MHz, including full wave polarization measurements. The measured linear dynamic range for broadband noise is higher than 60 dB. Thanks to its dynamic range, its excellent selectivity and accuracy, this receiver immediately appeared as a real improvement, in particular regarding the RF interference problem.

By means of the above described antennas and devices a great volume of radio astronomical observations have been carried out during the last years. The main part of the measured data is now processed. In this work we would like to present some previous results, which illustrate the new possibilities of the developed techniques and methods. The Jovian decameter emission obtained with the DSP installed to the UTR–2 radio telescope is shown in Figure 7. In the top panel the time resolution of measurements was 2 ms, and in the bottom panel 100 ms. Frequency resolution in these experiments was 20 kHz. Vertical dark lines indicate the quasi–monochromatic and monochromatic interferences reliably. Thanks to the very high dynamic range and resolution, the Jovian radio emission is recorded confidently (oblique lines in the picture) even in the presence of intensive interferences.

Solar burst radiation obtained during different day times is presented in Figure 8.

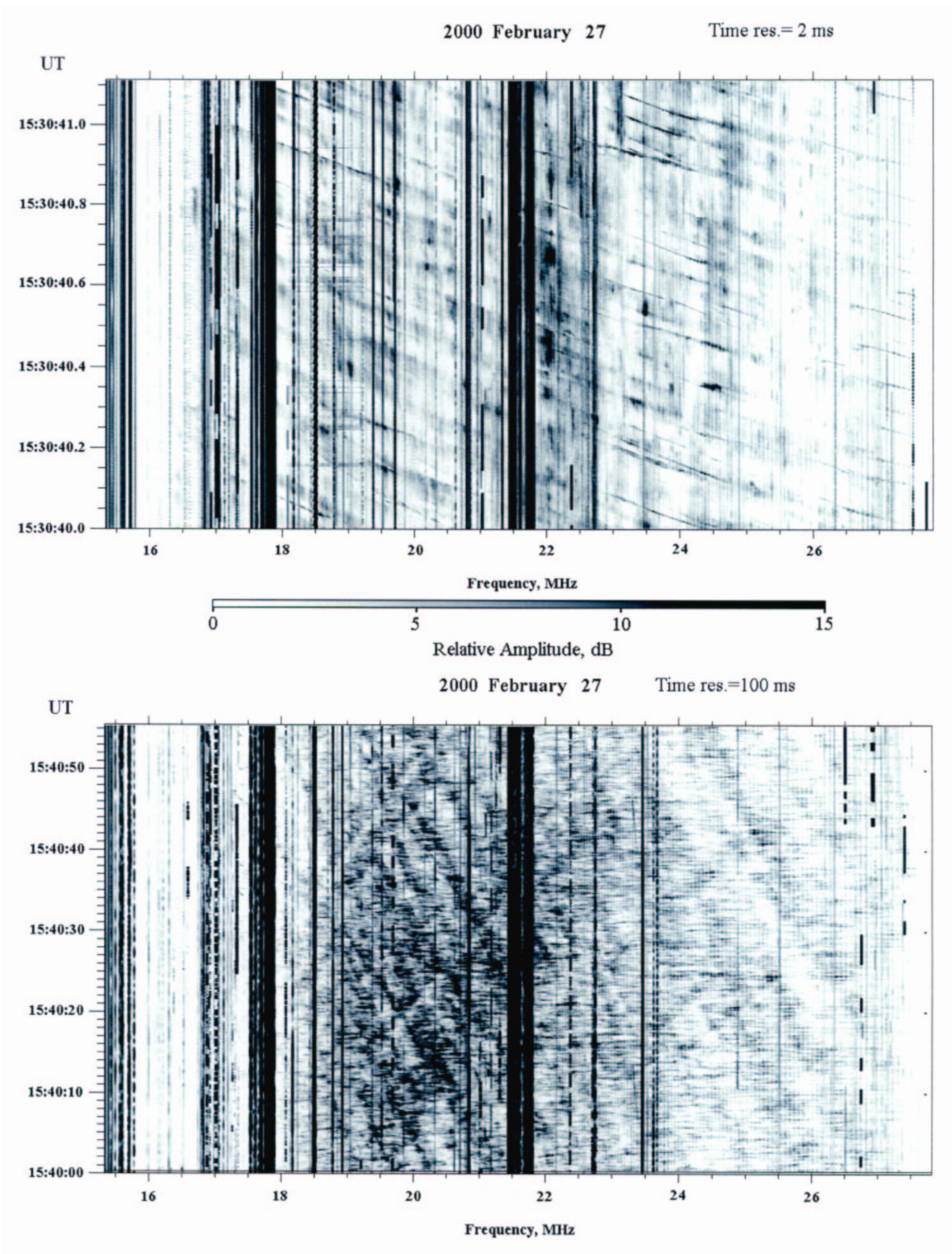

Figure 7: Jupiter observations with DSP (UTR–2, two time resolutions regimes).

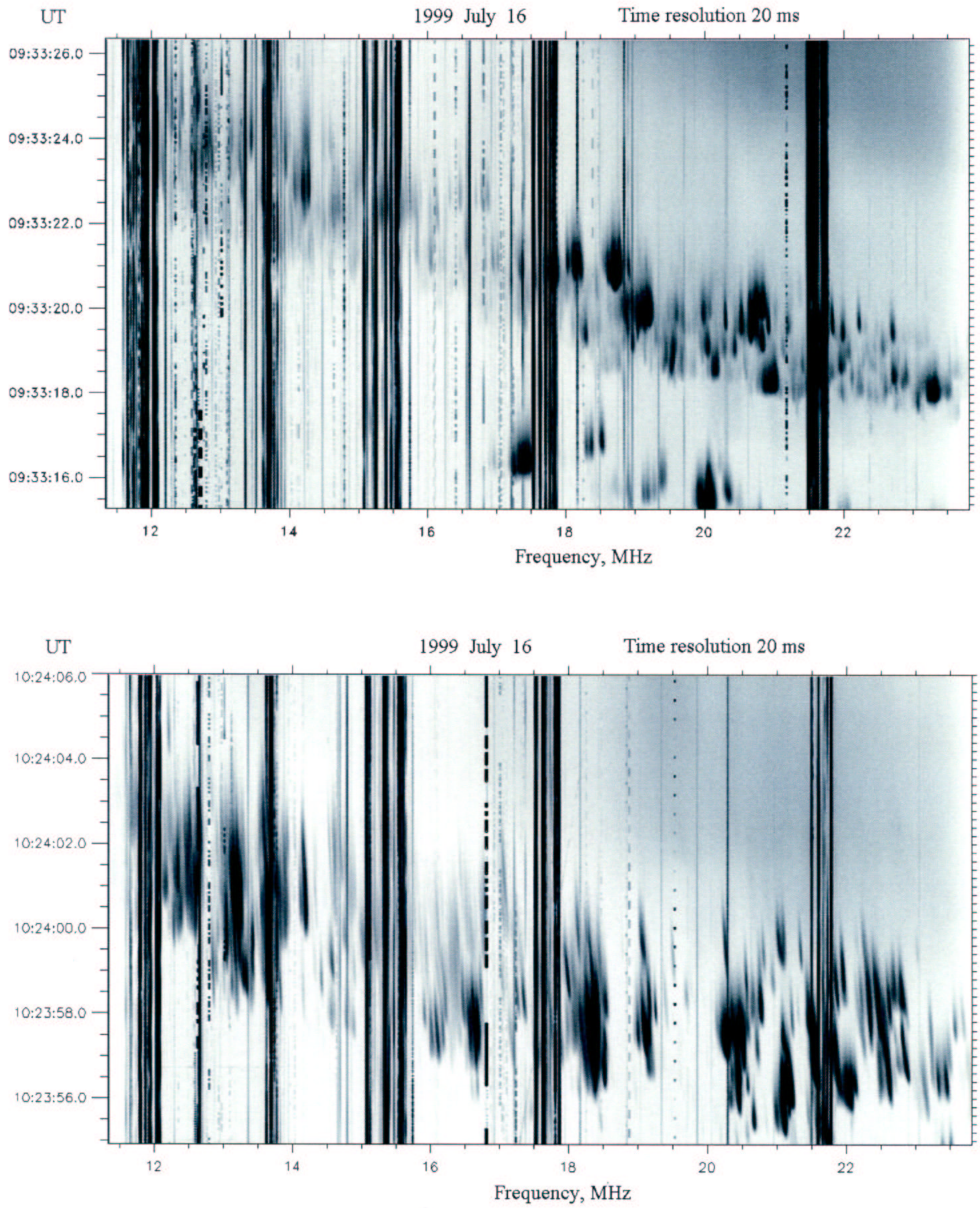

Figure 8: Chains of stria bursts. Fragments of the type IIIb–III bursts. UTR–2 Solar observations with DSP.

In Figure 9 also Solar burst emission is shown but with another characteristics. In particular, in Figure 8 one can see the groups of short narrow–band bursts against the background of type III solar bursts. High sensitivity of the telescope UTR–2 and high efficiency of the recording equipments allow the indication of different events even in the case when

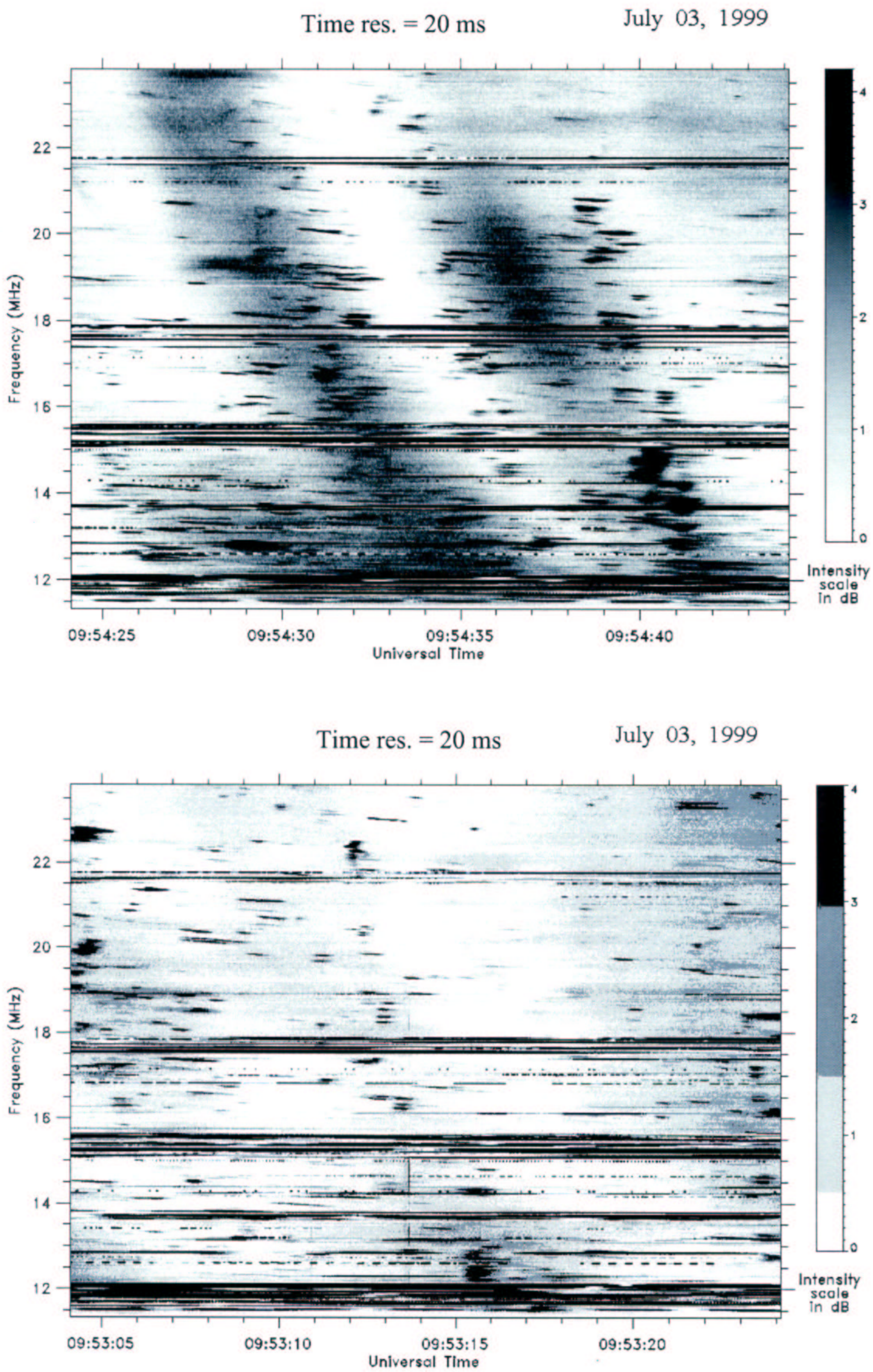

Figure 9: Groups of short, narrow band bursts. Fragments of the noise storm. UTR–2 Solar observations with DSP.

they have very low intensity.

New experimental possibilities of large antenna and new instrumentations manifest themselves also in Figure 10 where one can see the separate pulsar pulses.

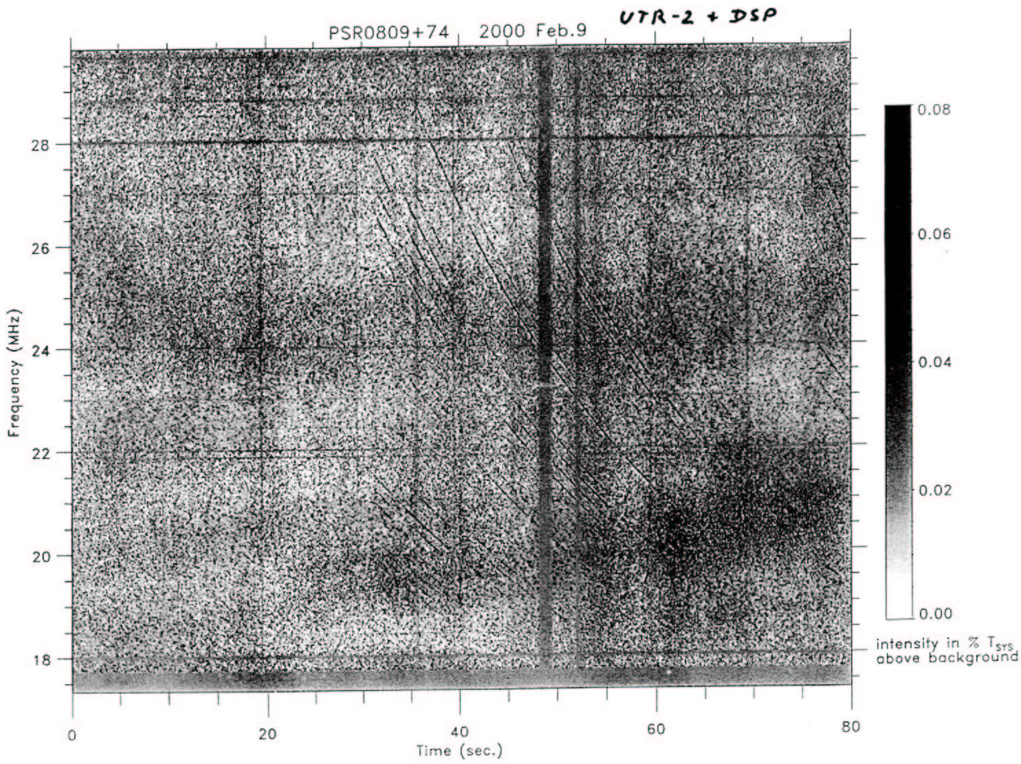

Figure 10: Dynamic spectrum of pulsar PSR0809+74.

In some cases waveform receiving techniques perform very effective results (see Leitner and Rucker [2001] in present book). The fine structure of the Jovian decameter emission obtained with the world largest telescope UTR–2 is presented in Figure 11.

The DAC potential is illustrated in Figure 12, where the interstellar recombination lines of hydrogen are displayed. This method allows to realize very high sensitivity and resolution. But because of 1–bit quantization it is better to use this technique for the extraction of the weak spectral components when the intensive interferences are absent. Results of the multitelescope observations are shown in Figure 13, where the Solar burst of type III, obtained simultaneously by the Nançay Decameter Array, UTR–2, URAN–2 and URAN–3, are presented.

4 Conclusion

Research interest in very low frequency radio astronomy (decameter wave range) has considerably increased during recent years. In spite of difficult and laborious means of performing qualitative measurements at such low frequencies, the high astrophysical value of the data yielded by this range justifies the efforts. Now, proposals to put low frequency radio astronomical instruments outside the Earth's ionosphere (in open space and on the Moon) are being actively developed. By this way the influence of a great number

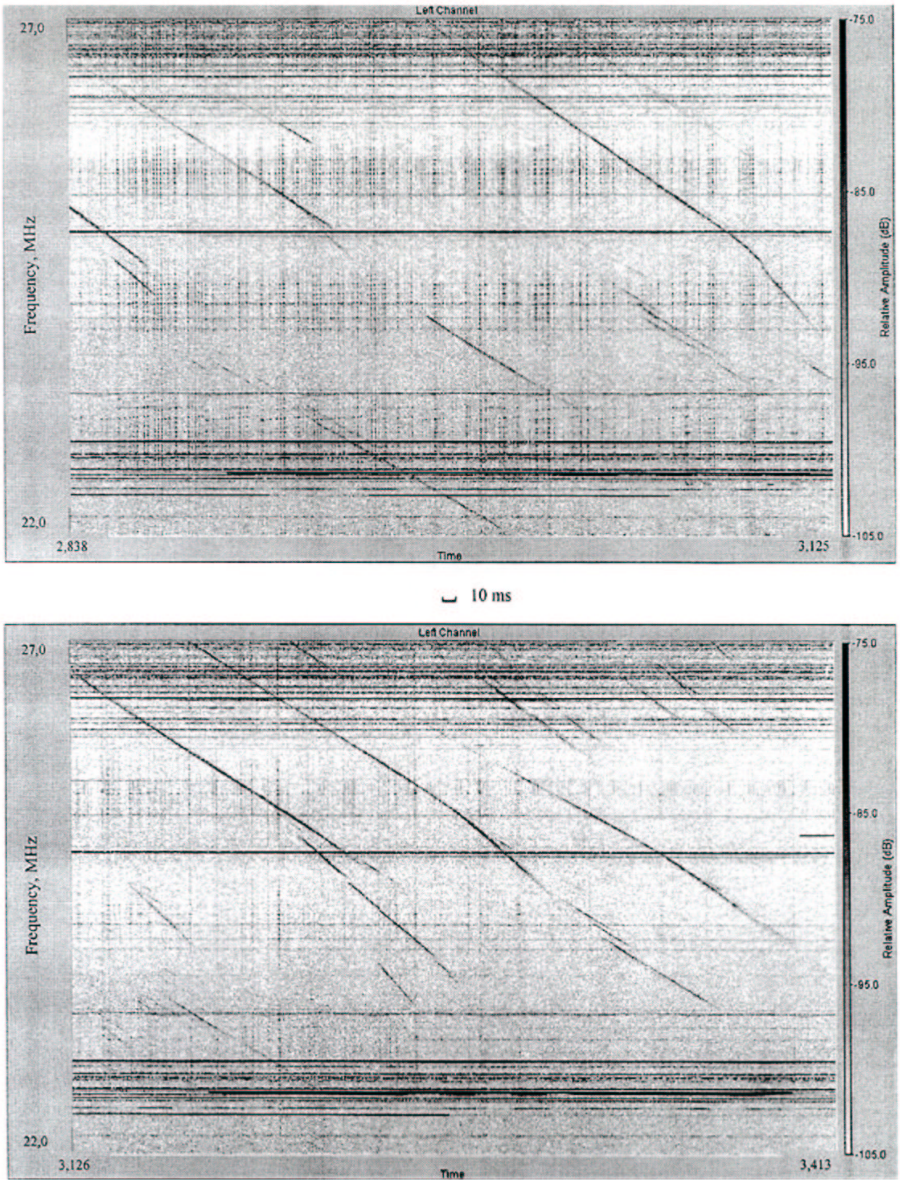

Figure 11: Fine structure of the Jovian radio emission. Fast AD converter (sample $f = 50$ *MHz). Start time: UT = 2000 February 26, 14:17:00.*

of "worsening" factors could dramatically be reduced. But the construction of a big "instant" effective area in space, which is indispensable for so many astrophysical investigations, is questionable. Therefore, development of ground–based decameter wave radio astronomy, including the upgrade of the biggest existing instruments, and the building of new telescopes with effective area up to 1,000,000 square meters, remains actual. Such an approach has gained support in the world's radio astronomy community. The maximum utilization of existing opportunities, and experience accumulated with the biggest low frequency instruments such as UTR–2, URAN and Nançay Decameter Array, is useful.

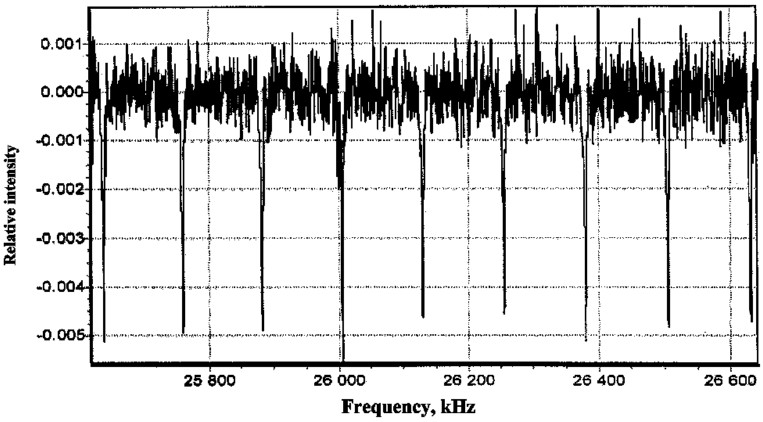

Figure 12: Carbon re–combination lines $C627\alpha$ - $C635\alpha$ in direction of Cassiopeia A.

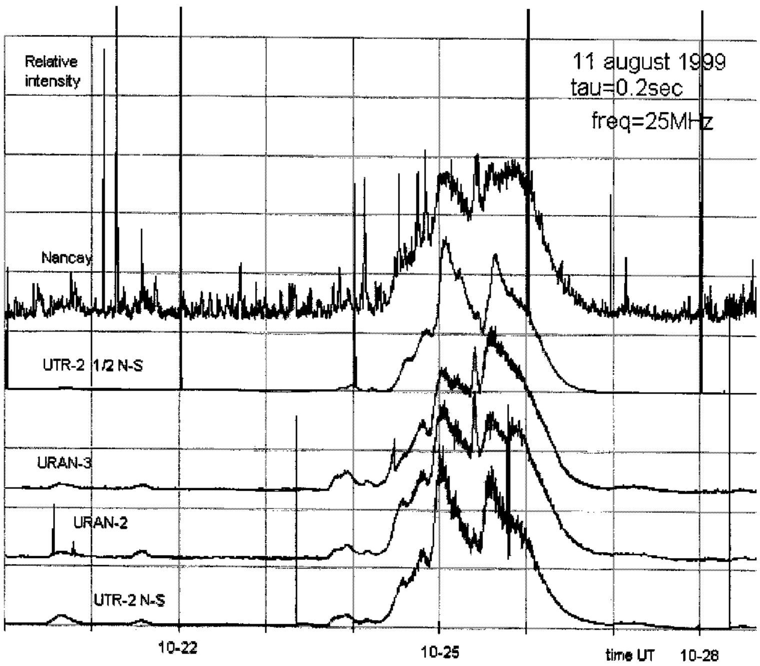

Figure 13: Multitelescope observations of Solar bursts.

The consolidation of efforts of the entire "low frequency" community seems to be natural.

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